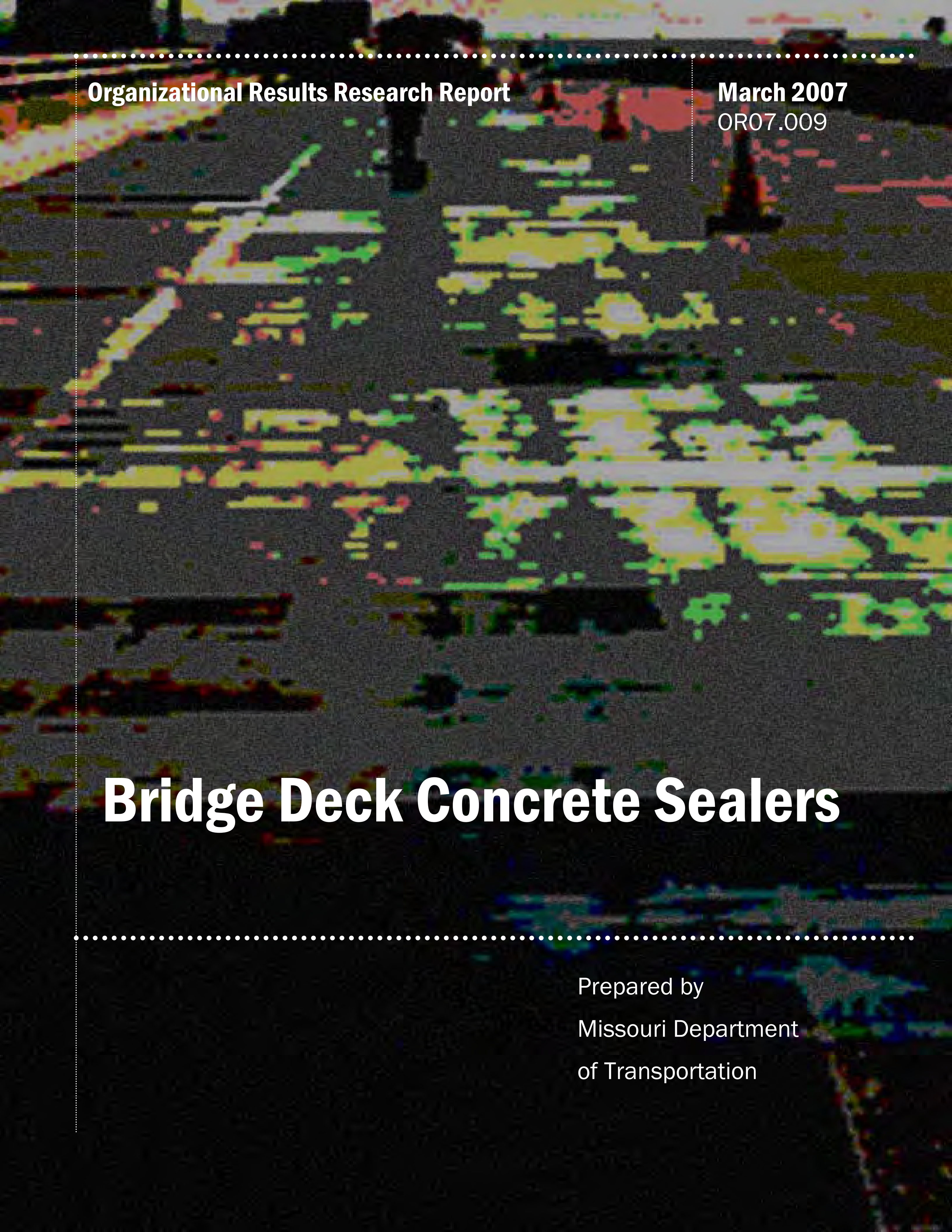

Organizational Results Research Report

March 2007
OR07.009

Bridge Deck Concrete Sealers

Prepared by
Missouri Department
of Transportation

FINAL REPORT

RI 04-051

Bridge Deck Concrete Sealers

Prepared for the
Missouri Department of Transportation
Organizational Results

by

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Missouri Department of Transportation

March 2007

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. OR07-009	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Bridge Deck Concrete Sealers		5. Report Date March 15, 2007
		6. Performing Organization Code RI04-051
7. Author(s) John D. Wenzlick		8. Performing Organization Report No.
9. Performing Organization Name and Address Missouri Department of Transportation Research, Development and Technology P. O. Box 270-Jefferson City, MO 65102		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Missouri Department of Transportation Research, Development and Technology P. O. Box 270-Jefferson City, MO 65102		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code

15. Supplementary Notes
The investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract
In the last several years, MoDOT has experienced problems with excessive amounts of cracking on some new concrete bridge decks. This has led to various concrete sealers being used for sealing cracks as well as whole decks, instead of applying linseed oil. Linseed oil is the only concrete sealer listed in Missouri's Standard Specifications, and is used for resistance to scaling on new bridge decks. Secondly, some recent projects re-texturing decks built with dense concrete overlays have specified penetrating concrete sealers. The concern was if linseed oil was used on the diamond ground surface, it might not have good frictional properties. Either extra linseed oil might be left on the surface or the linseed oil might not cure quickly enough to switch traffic onto it after short lane closures. It was decided that new penetrating sealers be used in these situations by special provision to the contract.

Four types of penetrating sealers were tested against linseed oil in the laboratory to rate their effectiveness, pick criteria for testing needed in accepting sealers and write a new specification to best protect concrete bridge decks from deterioration. In the case of new concrete decks it is recognized by American Concrete Institute that cracks smaller than 0.18 mm do not let chloride ions from salt penetrate through them. It was concluded that if there are very few cracks bigger than this, those cracks do not need to be sealed, and linseed oil can be used to help prevent scaling. If cracks were bigger than this it would be better to forego the linseed oil treatment and use a crack sealer. A table with concrete sealers classified into three performance groups is presented with the sealers ranked by performance and including cost per $ft.^2$.

It was found from this study that penetrating sealers are not good at sealing large cracks. Although an Ohio DOT test was used in this study to measure crack sealing capabilities, it did not give consistent answers. It did help identify what size cracks need to be sealed by a better crack sealer, such as a two-part epoxy. It was found that cracks in the range of 0.30 mm to 0.64 mm start to allow a saline solution to leak through the concrete very swiftly. So even if a penetrating sealer is used on a deck with many cracks, those 0.64 mm cracks and bigger need a more appropriate crack filler/sealer to seal the individual big cracks first.

Sealing cracks on existing older decks should be done using less expensive products that seal the entire small and medium-sized cracks and are effective for 2-4 years. A table listing these crack sealers is also presented. As a result of testing in this study one of these products was approved for preventive maintenance use statewide.

17. Key Words Concrete sealers, penetrating sealers, crack sealers		18. Distribution Statement No restrictions. This document is available to the public through National Technical Information Center, Springfield, Virginia 22161	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 47	22. Price NA

EXECUTIVE SUMMARY

In the last several years, MoDOT has experienced problems with excessive amounts of cracking on some new concrete bridge decks. This has led to the use of various concrete sealers to fill the cracks by applying the product to the whole deck surface, instead of applying linseed oil. Currently, linseed oil is applied to all new bridge decks in order to reduce scaling of the concrete surface; first by the contractor and a second time by maintenance forces one year after it has been open to traffic. Additionally, some resurfacing projects on major river bridges in the St. Louis area with existing dense concrete overlays have specified penetrating sealers. There were two concerns with putting linseed oil on these decks. First, dense concrete doesn't absorb linseed oil very well and may reduce tire friction if extra linseed oil is left on the surface. Second, the projects call for stage construction and there is only a short time for the linseed oil to cure before being opened to traffic. It was recommended that new penetrating sealers be used in these situations by special provision to the contract. Maintenance forces are also having to seal cracks on bridges a lot earlier in their lifespans and sometimes seal the entire deck surface. There appears to be a need for treating concrete bridge decks with other types of sealers in addition to linseed oil. These needs led to proposing this study to look at and test other types of concrete sealers.

While MoDOT has never found anything to perform better than linseed oil in more than 30 years of testing, this study looked at adjoining states and other DOTs to identify other potential concrete sealers and testing methods used to qualify these products. This study showed that none of the four penetrating sealers tested could pass both the tests that measure salt (chloride ion) penetration: the Salt-Scale Test (ASTM C672) and the 90-Day Ponding Test (AASHTO T259). None were close to the performance of the linseed oil, which passed both tests.

Therefore, the first recommendation of this study is that penetrating sealers continue to be used as warranted by circumstances of the project because of excess cracking of new decks and traffic handling problems allowing short curing time for linseed oil as explained above. Penetrating sealers should be allowed only by a special provision in the contract. The results of the tests done in this study alone do not indicate penetrating sealers should be added to the Standard Specifications.

Second, in the case of new concrete decks, it has been our experience *(and recognized by the American Concrete Institute)* that cracks smaller than 0.18 mm do not let chloride ions from salt penetrate through them. The 0.18 mm cracks are just wide enough to see at 5 feet from the surface. If there are very few cracks bigger than this, those cracks do not need to be sealed and linseed oil can be used to help prevent scaling and will also help seal the deck from chlorides. If cracks are bigger than this, it would be better to forego the linseed oil treatment and use a penetrating sealer.

Additionally, this study found that penetrating sealers are not good at sealing large cracks. It is recommended those products be put in a separate group called "Crack Sealers" and kept separate from "Concrete Sealers." Although the Ohio DOT test method was used to try and measure crack sealing capabilities, it did not give consistent answers. It did help quantify what size cracks need

to be sealed by a better crack sealer, such as a two-part epoxy. Cracks in the range of 0.30 mm to 0.64 mm start to allow a saline solution to leak through the concrete very swiftly. So, even if a penetrating sealer is used on a deck with many cracks, those 0.64 mm cracks and bigger, first need a more appropriate crack filler/sealer applied, such as an injected or surface applied two-part epoxy sealer. *(The crack width of 0.64 mm was picked because this is about the size that the epoxies will fill easily and also the cracks are usually smaller below the surface than they appear on top.)* Finally, one of the concrete sealers tested, acrylic-based Star Macro-Deck, also has shown to be a good crack sealer and is lower cost. It was recommended during this study, and accepted, for preventive maintenance use statewide to seal open cracks. It is similar to an asphalt-based product already used by maintenance forces. It was also the only sealer that passed the two tests picked for a new materials special provision.

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Investigator's Note: It came to our attention after this report was completed that the Water Soluble 1:1 product was supplied by the producer to MoDOT for testing at twice the strength (% solids) as it is sold in the market place. It was tested at Full Strength at 40% solids whereas it is sold Full Strength at 20% solids. The table shows the actual percent solids of polymers diluted with water for both Lab Testing and as sold to the consumer. This should be taken into account when looking at all tables and testing data dealing with the Water Soluble product in this report.

PERCENT SOLIDS

Dilution Rate	Lab Tested	Dilution Rate	Market Place
Full Strength	40%	------	-----
1:1	20%	Full Strength	20%
3;1	10%	1:1	10%

Present Conditions

Because of increased amounts of cracking being noticed on new bridge decks in the last few years the districts are using different types of sealers to seal these cracks. MoDOT has always used linseed oil as a scaling prevention treatment. Lately maintenance crews and Resident Engineer's offices have asked to use various sealers for sealing cracks as well as the concrete surface of the whole decks instead of linseed oil. Linseed oil is the best surface scaling preventer ever tested by MoDOT but isn't good as a crack sealer. Since MoDOT has never accepted these various types of sealers before, there are no criteria for acceptance to get them on to a pre-qualified materials list. Also AASHTO's National Transportation Product Evaluation Program (NTPEP) program is not testing this type product and doesn't plan to in the near future. For this reason an In-House study to come up with criteria for acceptance as well as to compare some of these new sealers for effectiveness versus linseed oil and each other was undertaken. Also since there is no current AASHTO or ASTM test for crack sealers, Ohio DOT's modified AASHTO T259 test using cracked beams was performed and the effectiveness of the method analyzed.

Objectives

The objective of the study was to come up with the right testing regime to qualify concrete sealer products. Sealers that have been used already by maintenance or construction; reactive silicates, silanes, and siloxanes were compared to linseed oil for scaling prevention. They were also tested on cracked concrete to establish their effectiveness in sealing cracks. If accepted MoDOT would have a testing regime established to accept concrete surface sealers that vendors can use to get on to a pre-qualified list.

Literature Search

Adjoining states and the states of Ohio, Texas and Wisconsin, who have studied these sealers in the past, were contacted to see what sealers they used, what their experiences with them were, and what specifications they used.
(See Table 1)

Table 1 - OTHER STATES CONCRETE SEALER SPECIFICATIONS

State	Test No.	Required to pass
Iowa (non-riding surfaces)	AASHTO T259	$\leq$ 10% of control at 1/16" – ½"
Illinois	Uses linseed oil for scaling like MoDOT	Specification
Kentucky (non-riding surfaces)	Freeze Thaw Test – 50 cycles Accelerated Weathering ASTM D822 Salt Spray Resistance ASTM B117 Fungus Growth Resistance FS TT-P-29	No visible defects Slight color change No loss of adhesion–300 cycles No growth @ 21 days
Tennessee	AASHTO T259 (90 day ponding)	Max. 1.0 pcy at ½"-1"
Arkansas (Silane or Siloxane)	ASTM C642 (Absorption) AASHTO T 259	48 hrs. – 1% by weight 50 days – 2% by weight 0.76 pcy at ½" – 1"
Oklahoma	Absorption - OHD L 39 (48hrs) Penetration – OHD L 40	1% max. by weight 0.15" min. depth
Kansas	No specifications for sealing riding surfaces	
Nebraska	AASHTO T259	0.76 pcy at ½" – 1"
Wisconsin	Allow penetrating sealers. No current sealer specification – 2005 University of Wisconsin – Madison has proposed some Performance Groups & guidelines	AASHTO T 259 – ½ of Cl^- as control ASTM C672 – Rating of 1 lower than untreated
Texas Item 428 – Prepare surface and apply linseed oil treatment or a penetrating-type sealant treatment to concrete.	DMS81-40 • Water repellency and depth penetration • Accelerated Weathering • Density (gallon weight) (ASTM D1475) • Infrared Spectrum • Gas chromatogram	• Max. 1.0% absorption • Penetration min. .25" • Max 2.25% absorp. After 1000 hrs. Weatherometer • Must not vary > 0.05 lb./gal. • Match pre-approved sample • Match chromatogram of pre-approved sample
Ohio Reactive Silicate (MoDOT's current Bridge Special Provision)	ASTM C 672 - Scaling Resistance ASTM C642 (Absorption) AASHTO T259 Modified, Crack Sealing ASTM E274 – Skid Resistance	• Rating = 0, no scaling after100 cycles (non-air entrained) • max. 1% 48 hrs., 2% - 50 days • time of second ponding/first ponding > 2 • shall not reduce > 10%

Technical Approach

Testing information from other states and MoDOT's familiarity with AASHTO T277, the Rapid Chloride Permeability Test, narrowed down the testing to the five test procedures used in this study. They are listed in the Table 2 along with the 4 different penetrating sealers that were tested, linseed oil and a control (un-sealed concrete).

Table 2 - Tests Performed in MoDOT Research Investigation of Concrete Sealers

Test No.	**Description**
AASHTO T259	Resistance of concrete to Chloride Ion Penetration (90 day ponding)
ASTM C672	Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
AASHTO T277	Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
ASTM C642	Standard Test Method for Density, Absorption, and Voids in Hardened Concrete
Ohio Modified T259	Crack Sealer Test - (2X unsealed time – minimum to pass)

Table 3 – Products Tested

Product	**Brand Name**
Linseed Oil	50/50, Double Boiled Linseed Oil/ Mineral Spirits
Reactive Silicate 1	Chem Tec One
Reactive Silicate 2	Radcon # 7
Water Soluble 1:1	Star Macro-Deck
Silane 55	Sil-Act ATS-55
Control Concrete	

Two different batches of Type B2 concrete mix, MoDOT's typical bridge deck mix, were used to cast test specimens. One mix was air entrained and one was not, to meet the different test method specifications.

The Type B2 concrete used contained the following ingredients:

Cement	7.5 bags Portland Cement - Continental Cement Co.
Fine Aggregate	Class A – Missouri River Sand
Coarse Aggregate	Limestone – Cedar Valley, Gradation D (Max. 1")
Water/Cement Ratio	0.40 max.
Air Entrained	5.0% minimum

Testing

The testing regime picked included the following tests.

Test 1. AASHTO T529, Standard Test Method for Resistance of Concrete to Chloride Ion Penetration. Test slabs made with air entrained concrete have a 3% sodium chloride solution ponded on them continuously for 90 days. (Hence the reason this test is often referred to as the 90-Day Ponding Test.) Before ponding liquid on them, the test slab surface shall be abraded using grinding or sandblasting if the concrete or treatment is subject to the wearing effect of vehicular traffic. If the concrete or treatment is to be used on surfaces not subject to wear then the abrading step shall be omitted. After 90 days the surface is left to dry, samples of pulverized concrete are taken and analyzed for percent chloride ions by AASHTO T260. Two samples (A & B) are taken at a depth of 1/16" to ½" and ½" to 1" and analyzed separately. The averages of the two samples (A & B) are shown at both depths (1/16"-1/2") and (1/2"-1") in Table 4 below. (The complete data is shown in Appendix B.) The (1/2"-1"), shown in red in the table is used in most state specifications for accepting sealers because narrower limits can be set at this depth.

Table 4 – Salt Ponding Test

AASHTO: T 259					
(90 day Ponding Panels)					
			Average		**Average**
		A	**(1/16"-1/2")**	**B**	**(1/2"-1")**
Sample #	**Treatment**	**#/cy**	**#/cy**	**#/cy**	**#/cy**
5RVWA036	Linseed Oil	4.21	4.41	0.39	0.49
5RVWA037	Linseed Oil	4.60		0.59	
5RVWA022	Reactive Silicate 1	10.53	9.75	0.20	0.62
5RVWA023	Reactive Silicate 1	8.97		1.05	
5RVWA008	Reactive Silicate 2	13.7	9.85	0.98	0.68
5RVWA009	Reactive Silicate 2	6.05		0.39	
5RVWA086	Water Soluble 1:1	6.24	8.19	1.09	0.88
5RVWA087	Water Soluble 1:1	10.14		0.66	
5RVWA050	Silane 55	9.95	7.41	1.17	0.78
5RVWA051	Silane 55	4.88		0.39	
5RVWA064	Uncoated	9.17	7.90	0.59	0.49
5RVWA065	Uncoated	6.63		0.39	

The test data showed that the average chloride value at (1/2" – 1") depth for all the specimens except the Water Soluble 1:1 and Silane 55 sealers were below the 0.76 pcy proposed for acceptance. There is however an anomaly in the data in that all the values were adjusted to remove the pcy of chloride, inherent in the sand and aggregate, from the original mix. With this done the uncoated samples had a value of 0.49 pcy, less than any of the penetrating type sealers and equal to the Linseed Oil.

Test 2. ASTM C672, Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals, commonly referred to as the Salt Scaling test, uses non-air-entrained concrete covered with a 4% calcium chloride and water solution and subjected to 24 hour alternate cycles of freezing at 0°F and then thawing at 73°F. Note 3 of the specification should be followed when evaluating penetration-type coatings for application to surfaces subject to traffic wear, "it may be desirable to abrade the treated surface of the test specimens by sufficient wire brushing to break any films remaining on the surface after drying." Generally the test is run for 50 cycles or 100 cycles while evaluating the surface condition every 5 cycles. The tests in this project were run at 50 cycles.

Table 5 - Scaling Resistance of Concrete Surfaces

ASTM C672

(Salt Scale Test)

Treatment	**50 Cycles**
Linseed Oil	0
Linseed Oil	0
Reactive Silicate 1	4
Reactive Silicate 1	4
Reactive Silicate 2	3
Reactive Silicate 2	3
Water Soluble 1:1	3
Water Soluble 1:1	3
Silane 55	2
Silane 55	2
Uncoated	4
Uncoated	4

RATING	**CONDITION OF SURFACE**
0	NO SCALING
1	VERY SLIGHT SCALING (1/8" (3.2 MM) DEPTH, MAX, NO COARSE AGGREGATE VISIBLE)
2	SLIGHT TO MODERATE SCALING
3	MODERATE SCALING (SOME COARSE AGGREGATE VISIBLE)
4	MODERATE TO SEVERE SCALING
5	SEVERE SCALING (COARSE AGGREGATE VISIBLE OVER ENTIRE SURFACE)

None of the sealers tested had a rating of "0" except for Linseed Oil. Kentucky calls for "0" scaling at 50 cycles. Ohio and Missouri's Bridge Special Provision for Reactive Silicate Sealers call for a rating of "0" at 100 cycles.
However, by Wisconsin's specifications all the sealers tested except the Reactive Silicate 1 would have passed their criteria of having a rating one lower than the Uncoated concrete sample (3). Examples of the conditions for each rating after the test was completed are pictured below.

Figure 1 – Salt Scale Panels

Linseed Oil 50 Cycles
Rating = 0

Silane 55 50 Cycles
Rating = 2

Reactive Silicate 1 50 cycles
Rating = 4

Test 3. AASHTO T277, Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, sometimes referred to as the Rapid Chloride Permeability Test**.** This test method covers the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. MoDOT has had good success using this method on core samples taken from bridge decks treated with concrete crack sealers, and has even used it in the past for acceptance of certain crack sealers for use by MoDOT maintenance forces. For this reason it was decided to include AASHTO T277 in the testing regime for this project. A summary of the results follows and full results are in Appendix B.

Table 6 - Rapid Chloride Permeability
AASHTO T277

Sample #	Product	Charge Passed (coulombs)	Average (coulombs)	Rating
5RVWA031	Linseed Oil	3801	3545	Moderate
5RVWA032	Linseed Oil	3289		
5RVWA018	Reactive Silicate 1	3721	3799	Moderate
5RVWA017	Reactive Silicate 1	3876		
5RVWA003	Reactive Silicate 2	3941	3771	Moderate
5RVWA004	Reactive Silicate 2	3600		
5RVWA077	Water Soluble 1:1	1959	1959	Low
5RVWA046	Silane 55	2418	2880	Moderate
5RVWA045	Silane 55			
5RVWA059	Control	3846	3914	Moderate
5RVWA060	Control	3981		

Key for Rapid Chloride Permeability Ratings

Chloride Permeability	Charge Passed (coulombs)	Type of Concrete
High	4,000	High w/c ratio (=>0.6)
Moderate	2,000-4,000	Mod. w/c ratio (0.4-0.5)
Low	1,000-2,000	Low w/c ratio ("Iowa" dense concrete)
Very Low	100-1,000	Latex Mod. Concrete Internally sealed
Negligible	100	Polymer Impregnated Polymer concrete

The chloride permeability of all of the samples but one tested in the “Moderate” range even the uncoated control. This would be expected of this Type B2 concrete, which has a water/cement ratio of 0.4. The only sealers that seemed to have an effect were the Silane 55 averaging 2880 and being on the low end of the “Moderate “ rating and the Water Soluble at 1959 being in the “Low “ range.

Test 4. ASTM C642, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. The forth test performed was the Absorption Test, which is part of ASTM C642. It was performed according to Oklahoma DOT’s Test Method OHD L-39. Several states use this test to assess the percent absorption of water when a sample of concrete or concrete with sealer applied is immersed in water. The standard test is to determine absorption after 2 days immersion, return the specimen to water and then recalculate percent absorption after 50 days. The most common limits set on absorption are 1% after 48 hrs. and 2% after 50 days, these are the limits this project set out to use as a standard for good sealer performance. None of the samples passed, however. A retest was done on some new samples and instead of using paraffin for a waterproof covering as suggested by Oklahoma’s specification, an epoxy covering was used on the sides and bottom, and the top covered with the sealer being tested. The only sample that passed, even on the re-test, was the Water-Soluble 1:1. A summary of the results follows and the complete testing results are included in Appendix B.

Table 7 – Absorption Test

ASTM C642 Modified

Absorption Test, OHD L-39

Oklahoma DOT - Method of Core Test For Determining Percent Moisture Absorption of Core to which Water Repellant Solution Has Been Applied

Sample Number	Treatment	% Absorption @ 48 hrs.	% Absorption @ 50 days
5RVWA040-A	Linseed Oil	3.469	3.959
5RVWA026-A	Reactive Silicate 1	3.093	4.263
5RVWA012-A	Reactive Silicate 2	2.523	3.951
5RVWA093-A	Water Soluble 1:1	0.835	2.790
5RVWA054-A	Silane 55	0.406	3.249
5RVWA040-B	None	3.800	4.169

Table 8 - Absorption Re-Tests

Treatment	% Absorption @ 48 hrs.	% Absorption @ 50 days
Linseed Oil	2.519	4.424
Reactive Silicate 1	3.238	4.420
Reactive Silicate 2	2.967	4.240
Water Soluble 1:1	0.364	1.094
Silane 55	0.669	2.604
None	2.981	4.526

Test 5. Crack Sealing Test, AASHTO T259 Modified. This was to try to establish a method of testing the ability of a sealer to effectively seal an open crack in concrete. The test method picked is one used by Ohio DOT which uses beams made of AASHTO T259 prescribed concrete. The beams are broken in three point bending, put back together and then water is ponded over the crack. The amount of time it takes water to seep through the crack and show up on the outside of the concrete beam is measured. The beam and crack are allowed to dry and then sealed per the manufacturers specifications. Then water again is ponded over the crack and the time for it to appear on the other side of the crack is again recorded. To pass the test the time taken for the water to leak on the sealed sample divided by the time from the unsealed concrete sample must be 2 or greater (or twice as long). A summary of the results follows and the complete testing results are included in Appendix B.

Table 9 - Crack Sealing Test

AASHTO T259 Modified

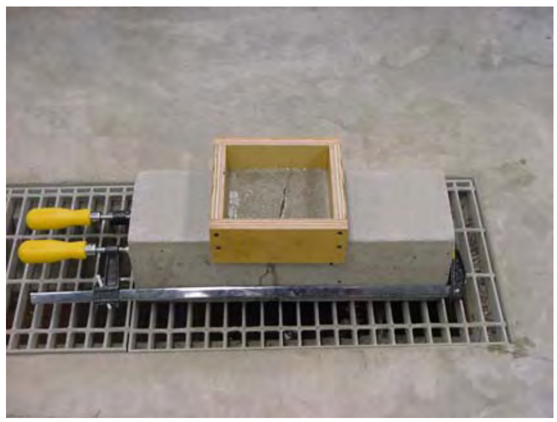
Sample Number	Surface Treatment	Average Crack Width	Elapsed Time Unsealed	Elapsed Time Sealed	Sealed Time/Unsealed Time = (>2 to pass)	Pass
5RVWA033	Linseed Oil	0.0767 mm	21 seconds	53 seconds	2.52	Yes
5RVWA019	Reactive Silicate 1	0.187 mm	9 seconds	3 seconds	0.33	No
5RVWA006	Reactive Silicate 2	0.300 mm	3 seconds	2 seconds	0.66	No
5RVWA080	Water Soluble 1:1	0.060 mm	9 seconds	59 seconds	6.55	Yes
5RVWA048	Silane 55	0.050 mm	12 seconds	777600 sec. 9 days (stopped test)	64800	Yes
5RVWA061	Control	0.323 mm	6 seconds	N/A	N/A	N/A

The Linseed Oil did well although this was a small crack at 0.0767 mm average crack width. The Water Soluble 1:1 also passed the test criteria of twice the time to leaking as the untreated crack but had an even smaller 0.060 mm crack. The Silane 55 at 0.050 mm was the smallest crack and the treated crack never leaked. The reactive silicates did not do well on this test at all and had the largest average crack widths at 0.187 mm and 0.3 mm. The manufactures claim that more time under saturated water conditions is needed for the silicate to react with the free lime in the concrete so this is a bad test for them. The American Concrete Institute (ACI) claims that a crack larger than 0.18 mm is needed for chlorides to intrude into the concrete. This test seems to depend on how well the beams are put back together after cracking. It appears that for this test to be more accurate a greater number of sample beams needs to be designated so each sealer can have two samples and perhaps the minimum average crack width should be required to be over 0.18 mm. Below is an example of a beam being tested both before and after the sealer was applied. This one failed the test.

Figure 2 – Crack Sealer Test

Reactive Silicate 2 test beam – average crack width 0.30 mm crack

Same beam before sealed test, leaked in 3 seconds.



Same beam after sealed, leaked in 2 seconds.

Costs

In order to determine the practicability of using various new concrete sealers it is necessary to look at the cost to see if MoDOT is getting the best value for their preventative maintenance dollars. Especially since the present practice of using linseed oil has been doing an excellent job of reducing scaling and resisting chloride contamination and is the least expensive. The table of concrete sealers below is for comparison of the general costs and area of coverage. Prices given are for materials only and are ranked from lowest to highest cost at the time of this study.

Table 10 – Cost of Concrete Sealers

Product Name	Manufacturer Expected Service Life	Sealer Appearance or Color	Coverage Sq.ft./gallon	**Cost** /sq.ft.
Linseed Oil 50/50 w/Mineral Spirits	5 yrs.	Clear	200	$ 0.02
Water Soluble 1:1	3 yrs.	Clear	200	$ 0.08
Silane 55	10 yrs.	Clear	150	$ 0.18
Reactive Silicate 1	10 yrs.	Clear	50 (Apply twice @ 100)	$ 0.18
High Molecular Weight Methacrylate	5 yrs.	Clear	180	$ 0.45
Reactive Silicate 2	10 yrs.	Clear	NA	$ 0.70

Costs: The table of crack sealers below is for comparison of the general costs and size of cracks they can seal. Prices given are for materials only and are ranked from lowest to highest cost at the time of this study.

Table 11 - Crack Sealers

Product Name	Manufacturer Expected Service Life	**Crack Width**			Sealer Appearance or Color	**Cost**
		<0.2mm Hairline	>0.2mm Narrow	>1mm Medium		
Star Macro Deck	3 yrs.	X	X	X	Clear	$ 0.08/sq.ft.
Pavon® Indeck	3 yrs.	X	X	X	Brown/black	$ 0.08/sq.ft
HMWMMA	5 yrs.	X			Clear	$ 0.45/sq.ft.

Proposed New Specification

From the testing done the question is does MoDOT need a new concrete sealer specification and what should it say? The alternatives are:

1. Do nothing and only allow Linseed oil for scaling resistance treatment
2. Use the tests studied in this investigation
   - Decide which tests to require
   - Set a performance limit as criteria

Assuming the second alternative, how were the merits of testing done by other states determined for Missouri's case?

Freeze Thaw (ASTM C666) – although MoDOT has the equipment to do this test, it is primarily used for accepting concrete aggregates, it is too time consuming and labor intensive for MoDOT to qualify many different concrete sealers.

Absorption – three versions of this test were run during this investigation.

1. First used was OHD L-39, Water Immersion Test for Determining Percent Moisture Absorption of Core Taken from Portland Cement Concrete to which Water Repellant Solution has been Applied. This is an Oklahoma DOT method tested which seals all but the top surface of a core with paraffin after oven dried as designated by ASTM C642 Test Method 5.1 and the subject sealer is applied to the top. All of the sealer samples failed the OHD L -39 criteria of a maximum 1% absorption in 2 days and 2% in 50 days. Since it was surmised that the imperfect application of paraffin might have let in moisture a few extra samples from the Reactive Silicate 1 sealer were re-tested using a different method.

2. One pair of cores was prepared using an epoxy coating instead of paraffin and two pairs using ASTM D6489, Standard Test Method for Determining the Water Absorption of Hardened Concrete Treated With a Water Repellent Coating, which treats all sides of samples completely with the subject sealer. Results at 48 hours showed two samples using ASTM D6489 already at 1.9% absorption. The pair of epoxy coated core using ASTM C642 Test Method 5.1 samples tested at 48 hours had only 0.12% absorption.

   Coating all four sides with sealer (D6489) didn't compare well with ASTM C642 in this trial; the absorption was already twice that recommended in the specification. Using epoxy sealer instead of paraffin to cover three sides showed much lower absorption at 24 hours. Intuitively, it was decided to use C642 Test Method 5.1 but use epoxy for the waterproof coating, and to re-test all five types of sealers again.

3. The third round of tests appears to be the most accurate. The test values are reported above in Testing section 4 as "Absorption Re-Tests". A suggested modification to ASTM C642 Test Method 5.1 has been written into the proposed Materials Special Provision, provided in Appendix A, designating using a two-part epoxy as the waterproof coating. It also appears that the test results may have been even more accurate if the

epoxy coating is overlapped on to the top surface 1/8 inch. This would stop any leaking around the ragged concrete edge at the top of the core.

Discussion

It is recommended **not** to use the following tests to qualify penetrating sealers:

- ASTM C672 (Scaling Resistance) and last 100 cycles with a rating = 0. [This is a very harsh test and if done to the specifications (for a riding surface- top surface abraded with a grinder or sandblasted before and wire brushed after sealer applied), and using 4% CaCl solution specified - none of the sealers or linseed oil can meet it at 100cycles. At 50 cycles with an abraded surface, only the linseed oil passed. - This researcher is not convinced that other agencies are running this test to the letter of the specification. If there is an exception to the test procedure it should be stated in the State or Private Laboratory report with the test findings, what the exception was. Iowa and Kentucky state that the test is done with a non-abraded surface. Illinois uses a modified test with a ratio of the subject sealer to the rating of an untreated specimen to 0.80 at 60 cycles. It has been MoDOT's opinion, as stated earlier, that for over 20 years the 90 day ponding and Salt Scale tests are the best tests to represent what a scaling treatment should protect the concrete from, chloride ions: but the penetrating sealers, at least those tested here can not pass the standard test. For right now it can not be determined from the limited testing done if the testing is being performed contrary to the specifications or if there is an underlying reason these sealers do not perform well on this test. So, reluctantly it is recommended not to include the Salt Scale Test.

- AASHTO T277 (Rapid Chloride Permeability) -This test is not specified by any of the other states. Two studies have shown it is questionable, in some instances stating different test results occur because of substitution of other cementitious materials or use of certain aggregates. However, this test has been shown to give good indication of a crack sealers ability to seal out chlorides and moisture when used by MoDOT to test cores from concrete on an existing deck. Care should be taken that it isn't used on samples from new bridge decks that may have new cementitious additives (fly ash, slag, silica fume) that may affect the test as mentioned earlier.

- The Ohio Modified T259 Crack test. The crack widths and condition of the beams is very hard to duplicate between specimens and the amounts of time for water to seep through were very wide ranging (fractions of a second to over 9 days). There is no way to verify the precision of this test method statistically. With some modifications to the test offered earlier in this report it may be useful, but we don't have confidence enough to use this in a specification. It would be nice to qualify treatments, as crack sealers but there are no good test methods out there. The University of Wisconsin –Madison study done in 2005 presents a good crack sealer test using both bond strength and durability tests, which may be promising.

Refer to Table 12 for a summary of testing results. The numerical results and whether the sealer passed or failed are listed below the columns for each test. It is recommended that MoDOT's best course of action is to include two tests out of the five tests that were run. They are 90-day Ponding Test, AASHTO T259, and Absorption Test, ASTM 642 modified using epoxy sealer with the parameters listed and shown highlighted in the table.

Table 12 - Overall Test Results for Concrete Sealers

Product	AASHTO T259 (90 day ponding) (1/2"-1") #/cy	ASTM C672 Salt Scaling (0-5) (50 cycles, abraded)	AASHTO T277 Rapid Chloride Permeability (56 days)	ASTM C642 Absorption (ASTM D6489) Re-Test			Ohio Modified T259 Crack Test (2X unsealed time minimum to pass)
				48 hrs.	50 Day		
Linseed Oil	0.1 P(IA) P(TN)	0	3545 F	2.519	4.424	F	Pass
Reactive Silicate 1	0.62 P(AR) P(TN)	4	3798 F	3.238	4.420	F	Fail
Reactive Silicate 2	0.68 P(AR) P(TN)	3	3771 F	2.967	4.240	F	Fail
Water Soluble 1:1	0.88 F(AR) P(TN)	3	1959 (<1000^{+}) P	0.364	1.094	F	Pass
Silane 55	0.78 P(IA) P(TN)	2	2879 (<1000^{+}) P	0.669	2.604	F	Pass
Control Concrete	0.49 N/A	4	3914	2.981	4.526		N/A
	Arkansas - <0.76pcy @ ½"-1" Tennessee - Max. 1.0 pcy at ½"-1"			**1% @ 48hrs** and/or 2% @ 50 days			

Class 3, High Molecular Weight Methacrylate, was not tested in this study. It is included because it has been used in the past with MoDOT's permission and is a very good surface and crack sealer, but it is very expensive. High Molecular Weight Methacrylate should be accepted by certification as listed in the proposed Materials Special Provision.

From testing done in this research only one sealer would go on the Pre Qualified List if the Materials Special Provision is adopted. This sealer is listed generically as Water Soluble 1:1 (at a 1:1 ratio with water only). Silane 55 (Silane containing 55% solids) was the only product that was close to meeting the absorption test. With additional testing Silane 55 and other sealers may qualify, but additional independent testing will have to be submitted to MoDOT for approval as no other testing is planned on new products in this research study.

After looking at the test data it is recommended that the Soluble Reactive Silicates be left out the specifications for concrete sealers at this time. Manufacturer's literature claims a life of up to 10 years on Soluble Reactive Silicates but the testing done here had both SRS sealers doing the worst in 4 of 5 tests. They have been used by Bridge Special Provision on a few construction projects. Even though accepted by certified independent lab tests, some deficiencies were later found in those tests which make them void. After approval, further investigation noted deficiencies in the testing methods and the testing results provided to MoDOT. Specifically ASTM C672, section 9.1 using 4% calcium chloride solution was not met as the laboratory used

a less corrosive solution of 3% sodium chloride (called for in AASHTO T259) and did not wire brush the sealer off of the surface as called for in Note 3 of section 8.1 (if sealer is to be used on pavement surfaces subject to traffic wear).
Finally, if tested using any variations to the test method, the manufacturer should note this in his report even though the specification may not specifically require it.

Recommendation

The two tests listed below should be incorporated into a Materials Special Provision (see attached MSP).

1. All sealers must pass AASHTO T259 (90 day ponding) and have less than 1.00 pcy chloride at ½”-1” depth sample. (Originally a maximum of 0.76 pcy Cl^- was going to be recommended. This would be inline with more states specifications but could only be met by one set of products in this test. Because there is a need on some projects for this kind of sealer it was relaxed to 1.00 pcy.)
2. All sealers must pass ASTM C642 (Absorption) as modified and have absorption of not more than 1% after immersion for 48 hours in water and 2% at 50 days.

A Materials Special Provision has been written with hopes of getting into the Missouri Standard Specifications in the future. This would replace the current Bridge Special Provision for Soluble Reactive Silicates (SRS) sealants, which is the only type of penetrating sealer MoDOT has allowed so far. Replacing this Bridge special with the proposed MSP would open up three other classes of sealers for use when needed.

Implementation Plan

It is the recommendation of this study that a Materials Special Provision for concrete sealers, beyond linseed oil that is already in the Standard Specifications, should be adopted by the Construction and Materials Division. A proposed special provision can be found in Appendix A. Adoption of the special provision may require adding a new Test Method for the Absorption Test, which is a modification of ASTM C-642. However, concise language has been added to the proposed MSP in section 2.1.1.1 about the preparation of test cores, which should preclude the necessity of a new test method.

Adopting a new special provision would allow more types of sealers to be available for special construction needs as they come up in future projects than the current SRS Bridge Special Provision. Implementation should be considered immediately since there are currently projects being designed which are planning to use surface sealing as a less expensive alternative for sealing bridge decks currently in good condition. Right now these bridges would probably receive an epoxy polymer overlay at many times the cost. The long-term objective would be to see how many sealers would qualify to be put on a list and how they would perform in the field with time. If the sealers work well then the special provision should be revised and worked into the Standard Specifications section 703.3.8, Surface Sealing for Concrete. As new sealers come along they can be added to the list as new classes of surface sealers for concrete along with the solitary listed linseed oil.

Affected Business Units

The Construction and Materials division is the chief business unit to approve any Materials Special Provision and affected by having to certify any new products for prequalification, and also enforcement of construction requirements.

Design and Bridge Divisions would have several new products they could specify for certain special applications. Such things as diamond grinding of deck surfaces in congested metropolitan areas to get traffic back on the decks quicker. This has already been done on several Missouri and Mississippi River bridges with Soluble Reactive Silicates.

Use of concrete sealers for preventive maintenance of bridge decks has also been mentioned. Maintenance Division would have another, more economical, way of keeping chlorides and moisture out of decks still in satisfactory or good condition. One sealer, the water soluble sealer, was accepted as a crack sealer from further testing done in this study. Maintenance crews now have a choice between the current asphalt based product they are using, Pavon® In-Deck, which turns the deck black until it is worn off the surface to the new water soluble which dries almost clear in color.

Technology Transfer

Organizational Results will help with any information during the adoption of a Materials Special Provision and help in certifications of products if needed.

It will provide information to designers or maintenance personnel on manufacturers and suppliers of these products and the recommended application procedures. Organizational Results would like to be notified of applications of the first time use of these sealers so it can observe the application. Follow up information on the effectiveness of the field application of these sealers will be useful information and if needed Organizational Results staff can conduct additional testing in the field.

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American Concrete Institute Manual of Practices, 1997 Edition ACI 224R, 4.4, Table 4.1 Crack Widths in Concrete Bridge Decks

Appendix A

Proposed Materials Special Provision

PROTECTIVE SURFACE TREATMENT FOR CONCRETE – PENETRATING SEALERS

1.0 Description. This work shall consist of preparing and treating Portland cement concrete bridge deck and bridge approach slab surfaces with a penetrating sealer meeting this specification. This type of sealer shall be used in lieu of the normal surface sealing for concrete in accordance with Sec 703.

2.0 Materials. The protective surface treatment shall meet one of the three classes of penetrating sealers in accordance with this job special provision. The penetrating sealer selected by the contractor shall be submitted to the engineer for approval 30 days before application and shall be listed on MoDOT's Pre-Qualified Product List. The submittal shall include certified test data from an independent test laboratory and the application rate at which penetrating sealer was tested. The penetrating sealer shall be delivered pre-mixed and ready to use. Mixing/agitation shall be in accordance with the manufacturer's recommended procedures. The penetrating sealer shall be stored in tightly sealed containers in a dry location and as recommended by the manufacturer.

2.1 Class 1 Penetration Sealer – Water Soluble. The protective surface treatment shall be a 100 percent acrylic latex specialty additive or similar water soluble mixture with the percent solids clearly specified by the manufacturer. The treatment system shall meet the performance requirements listed in section 2.2.3 of this job special provision based on a single application at the manufacturer's recommended application rate.

2.1.1 Absorption. The absorption of the treated concrete under total immersion shall not exceed 1.0 percent after 48 hours or 2.0 percent after 50 days per ASTM C 642 as modified below for non-air entrained concrete. Concrete shall be proportioned and mixed in accordance with ASTM C 672.

2.1.1.1 In addition to ASTM C 642 section 4.1, one 4-inch (10 cm) diameter by 4 inch (10 cm) long core shall be retrieved from the surface of a Portland cement concrete to which penetrating sealer solution has been applied. The core shall be oven dried as designated by ASTM C 642 section 5.1. The core shall be sealed with a rapid setting coating on the sides and bottom. The coating shall overlap the top edge of the core 1/8" (3mm). The core shall be weighed to determine the oven dry weight (mass) of the core and coating. The weight (mass) shall be designated as "A".

2.1.1.2 The core, processed in accordance with section 2.1.1.1 of this job special provision, shall be immersed in a suitable receptacle and covered with tap water. The procedure as designated by ASTM C 642 section 5.2 shall be followed to determine the soaked surface dry weight (mass) of the core and coating. This weight (mass) shall be designated as "B".

2.1.1.3 The percent moisture absorption of the core shall be determined by ASTM C 642 section 6.1, equation (1). ASTM C 642 sections 5.3, 5.4, 6.1 and equations (2) through (7) shall not apply.

2.1.2 Salt water ponding. After 90 days ponding of 3 percent NaCl solution per ASSHTO T 259, the chloride ion content of the concrete shall not exceed 1.00 lbs/cu yd (0.45 kg/m^3) at ½ to 1 inch (13 to 25 mm) depth.

2.1.3 Skid resistance. The skid resistance of the treated concrete deck shall not reduce by more than 10 percent as compared to the same untreated concrete deck. A 5 test average shall

be performed in accordance with ASTM E 274 using ASTM E 501 ribbed tire at 40 mph (64 kph).

2.2 Class 2 Penetrating Sealers - Organo Silicon Compound. The protective surface treatment shall be an organo silicon compound dissolved in a suitable solvent carrier that, when applied, shall produce a hydrophobic surface covalently bonded to the concrete. The organo silicon compound shall be either alkyl-alkoxysilane or oligomerous alkyl-alkoxysiloxane. The solvent shall leave a residue of less than 1 percent by weight (mass) after evaporation.

2.2.1 The sealer shall not permanently stain, discolor or darken the concrete. Application of the sealer shall not alter the surface texture or form a coating on the concrete surfaces. Treated concrete shall be surface dry within 30 minutes after application.

2.2.2 The sealer shall be tinted with a fugitive dye to enable the sealer to be visible on the treated concrete surface for at least 4 hours after application. The fugitive dye shall not be conspicuous more than 7 days after application when exposed to direct sunlight.

2.2.3 The material shall meet the following performance criteria based on a single application at the manufacturer's recommended application rate.

Test	**Test Method**	**Duration**	**Max Absorption / Cl^-**
Water Immersion	ASTM C 642	48 hours	1 percent by weight (mass)
Water Immersion	ASTM C 642	50 days	2 percent by weight (mass)
Salt Water Ponding (based on non-abraded specimen)	AASHTO T 259	90 days	1.00 lbs/cu yd (0.45 kg/m^3) Cl^- Depth: (1/2 to 1") (13 to 25 mm)

2.2.4 The sealer shall be delivered to the project in unopened containers with the manufacturer's label identifying the product and with the seal(s) intact. Each container shall be clearly marked by the manufacturer with the following information:

- Manufacturer's name and address.
- Product name.
- Date of manufacture and expiration date.
- Lot identification.
- Storage requirements.

2.2.5 The sealer shall be used as supplied unless otherwise specified by the manufacturer. If the manufacturer specifies dilution, the requirements for such dilution shall be shown on the label of each container.

2.4 Class 3 Penetrating Sealer – High Molecular Weight Methacrylate. The material used shall be a low viscosity, non-fuming, and high molecular weight methacrylate resin in accordance with the following:

Property	**Test Method**	**Requirement**
Viscosity	Brookfield RVT 100 RPM @ 72°F (22°C)	25 cps maximum
Pot Life	Application life before curing begins [@ 68°F (20°C) air temperature]	15 minutes minimum
Curing Time	On site at 50°F (10°C)	6 hours Maximum

3.0 Construction Requirements.

3.1 Equipment. Application equipment shall be as recommended by the manufacturer. The spray equipment, tanks, hoses, brooms, rollers, coaters, squeegees, etc. shall be thoroughly clean, free of foreign matter, oil residue and water prior to applying the treatment.

3.2 Cleaning and Surface Preparation. Surfaces, which are to be treated, shall meet the approved product's requirements for surface condition. Sealing shall not be done until all concrete repairs and any corrective actions needed have been completed and cured. The contractor shall furnish the engineer with written instructions for surface preparation requirements and a representative of the manufacturer shall be present to assure that the surface condition meets the manufacturer's requirements.

3.2.1 Sealing shall be done after the bridge deck and bridge approach slabs have been textured.

3.2.2 At a minimum, the surface shall be thoroughly cleaned to remove dust, dirt, oil, wax, curing components, efflorescence, laitance, coatings and other foreign materials. The manufacturer or manufacturer's representative shall approve the use of chemicals and other cleaning compounds to facilitate the removal of these foreign materials before use. The treatment shall be applied within 48 hours following surface preparation.

3.2.3 Cleaning equipment shall be fitted with suitable traps, filters, drip pans and other devices to prevent oil and other foreign material from being deposited on the surface.

3.3 Test Application. Prior to final application, the contractor shall treat a measured test coverage area on horizontal and vertical surfaces of the different components of the structure to be treated for the purpose of demonstrating the desired physical and visual effect on an application or of obtaining a visual illustration of the absorption necessary to achieve the specified coverage rate. In the latter case, the applicator shall use at least ½ gallon (1.9 liter) of treatment following the manufacturer's recommended method of application for the total of the test surfaces. Horizontal test surfaces shall be located on the deck and on the curb or sidewalk, and vertical test surfaces shall be located on a parapet or safety barrier curb so that the different textures are displayed.

3.4 Application. The concrete treatment shall be applied to concrete surfaces as designated on the plans. The penetrating sealer shall be applied by thoroughly saturating the concrete surfaces at an application rate specified by the manufacturer and as shown in the approved certified test data.

3.4.1 The concrete surface temperature shall be above 35°F (2°C).

3.4.2 The treatment shall be spread from puddles to dry areas.

3.4.3 If the applicator is unable to complete the entire application continuously, the location where the application was stopped shall be noted and clearly marked.

3.5 Protection of Adjoining Surfaces and the Public.

3.5.1 When applying a treatment, the contractor shall protect adjoining surfaces of the structure that are not to be sealed by masking off or by other means. The contractor shall also make

provision to protect the public when treating the fascia of a bridge that spans an area used by the public.

3.5.2 Asphalt and mastic type surfaces shall be protected from spillage and heavy overspray. Joint sealants, traffic paints and asphalt overlays may be applied to the treated surfaces 48 hours after the treatment has been applied. Adjoining and nearby surfaces of aluminum or glass shall be covered where there is possibility of the treatment being deposited on the surfaces. Plants and vegetation shall be protected from overspray by covering with drop cloths. Precautions shall be followed as indicated on the manufacturer's material and safety data sheet.

3.6 Opening to Traffic. Traffic shall be allowed on a deck only after a treated area does not track.

4.0 Method of Measurement. Measurement will be made to the nearest square yard (m^2) measured longitudinally from end of the bridge approach slab to end of the bridge approach slab and transversely from roadway face of curb to roadway face of curb extended to end of the approach slabs. No deduction will be made for gaps to avoid, raised pavement markers, manholes or other obstructions. Material placed on curb faces will not be measured. Final measurement will not be made except for authorized changes during construction or where appreciable errors are found in the contract quantity. The revision or correction will be computed and added to or deducted from the contract quantity.

5.0 Basis of Payment. Payment for the above described work, including all material, equipment, labor and any other incidental work necessary to complete this item, will be considered completely covered by the contract unit price for "Penetrating Sealers".

Appendix B

Complete Results of Testing

Note: See next page for full test results in pounds per cubic yard.

Resistance of Concrete to Chloride Ion Penetration

AASHTO: T 259 (Ponding Panels)

Correction for chloride in original concrete ingredients

Project: RI04-051

		Sample 1			Sample 2		
		A			A		
Sample #	**Treatment**	%	**Base**	**NET**	%	**Base**	**NET**
5RVWA035	Uncoated	0.01			0.004		
5RVWA036	Linseed Oil	0.10	0.01	0.090	0.13	0.004	0.126
5RVWA037	Linseed Oil	0.13	0.01	0.120	0.12	0.004	0.116
5RVWA049	Uncoated	0.01			0.01		
5RVWA050	Silane 55	0.32	0.01	0.310	0.21	0.01	0.200
5RVWA051	Silane 55	0.10	0.01	0.090	0.17	0.01	0.160
5RVWA063	Uncoated	0.01			0.01		
5RVWA064	Uncoated	0.26	0.01	0.250	0.23	0.01	0.220
5RVWA065	Uncoated	0.15	0.01	0.140	0.21	0.01	0.200
5RVWA086	Star Macro 1:1	0.19	0.01	0.180	0.15	0.01	0.140
5RVWA087	Star Macro 1:1	0.30	0.01	0.290	0.24	0.01	0.230
5RVWA083	Uncoated	0.01			0.01		
5RVWA084	Star Macro F.S.	0.19	0.01	0.180	0.28	0.01	0.270
5RVWA085	Star Macro F.S.	0.19	0.01	0.180	0.26	0.01	0.250
5RVWA088	Star Macro 1:3	0.29	0.01	0.280	0.23	0.01	0.220
5RVWA089	Star Macro 1:3	0.24	0.01	0.230	0.22	0.01	0.210
5RVWA021	Uncoated	0.01			0.01		
5RVWA022	Chem Tech One	0.28	0.01	0.270	0.28	0.01	0.270
5RVWA023	Chem Tech One	0.23	0.01	0.220	0.25	0.01	0.240
5RVWA007	Uncoated	0.01			0.01		
5RVWA008	Radcon #7	0.37	0.01	0.360	0.35	0.01	0.340
5RVWA009	Radcon #7	0.13	0.01	0.120	0.20	0.01	0.190

AASHTO: T 259 Resistance of Concrete to Chloride Ion Penetration (Ponding Panels) – Cl^- in pounds per cubic yard.

	Sample 1				Sample 2								
	A		B		A		B		A	Avg. A	B	Avg. B	Arkansas 0.76 #/cy
Treatment	NET%	#/cy	NET%	#/cy	NET%	#/cy	NET%	#/cy	#/cy	#/cy	#/cy	#/cy	
Uncoated	0.25	9.75	0.020	0.78	0.22	8.58	0.010	0.39	9.17	7.90	0.59	0.49	
Uncoated	0.14	5.46	0.000	0.00	0.20	7.80	0.020	0.78	6.63		0.39		
Linseed Oil	0.09	3.51	0.010	0.39	0.13	4.91	0.017	0.66	4.21	4.41	0.53	0.43	P
Linseed Oil	0.12	4.68	0.010	0.39	0.12	4.52	0.007	0.27	4.60		0.33		
Chem Tech One	0.27	10.53	0.010	0.39	0.27	10.53	0.017	0.66	10.53	9.75	0.53	0.62	P
Chem Tech One	0.22	8.58	0.000	0.00	0.24	9.36	0.037	1.44	8.97		0.72		
Radcon #7	0.36	14.04	0.050	1.95	0.34	13.26	0.020	0.78	13.65	9.85	1.37	0.68	P
Radcon #7	0.12	4.68	0.000	0.00	0.19	7.41	0.000	0.00	6.05		0.00		
Silane 55	0.31	12.09	0.060	2.34	0.20	7.80	0.010	0.39	9.95	7.41	1.37	0.78	F
Silane 55	0.09	3.51	0.000	0.00	0.16	6.24	0.010	0.39	4.88		0.20		
Star Macro 1:1	0.18	7.02	0.018	0.70	0.14	5.46	0.017	0.66	6.24	8.19	0.68	0.88	F
Star Macro 1:1	0.29	11.31	0.038	1.48	0.23	8.97	0.017	0.66	10.14		1.07		

Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

ASTM C672

Sample Number	Surface Area (Sq. In.)	Surface Treatment	Visual Rating: 5 Cycles	10 Cycles	15 Cycles	20 Cycles	25 Cycles	30 Cycles	35 Cycles	40 Cycles	45 Cycles	50 Cycles	Rank
5RVWA041	107.1	Linseed Oil	0	0	0	0	0	0	0	0	0	0	1
5RVWA042	100.8	Linseed Oil	0	0	0	0	0	0	0	0	0	0	
5RVWA055	96.28	Silane 55	0	0	0	0	0	0	0	1	2	2	2
5RVWA056	102.5	Silane 55	0	0	0	0	0	0	0	1	2	2	
5RVWA013	98.3	Radcon #7	0	1	1	1	2	2	2	2	2	3	3
5RVWA014	79.7	Radcon #7	0	1	2	2	2	2	2	3	3	3	
* 5RVWA096	79.07	Star Macro F/S	0	1	1	1	1	2	2	2	3	3	4
* 5RVWA097	78.75	Star Macro F/S	0	0	1	1	1	2	2	2	2	3	
5RVWA098	96.2	Star Macro 1:1	0	1	1	1	1	2	2	2	2	3	5
5RVWA099	96.28	Star Macro 1:1	0	0	1	1	1	2	2	2	2	3	
5RVWA100	99.58	Star Macro 1:3	0	1	1	1	2	2	2	2	2	3	6
5RVWA101	105.45	Star Macro 1:3	0	0	1	1	1	2	2	2	2	3	
5RVWA027	97.89	Chem Tech 1	0	1	2	2	3	3	3	3	4	4	7
5RVWA028	86.94	Chem Tech 1	0	1	2	2	3	3	3	4	4	4	
5RVWA069	96.28	None	1	1	1	2	2	3	3	3	4	4	8
5RVWA070	103.78	None	1	1	2	2	3	3	3	3	4	4	
5RVWA095	102.93	None	1	1	2	2	3	3	3	3	4	4	

Curing

1-14 days	Moist Cure
15-28 days	Air Dry
@ 21 days	Treatment Applied
@ 28 days	Began Test

* Treatment applied at 28 days, test started at 35 days.

RATING	CONDITION OF SURFACE
0	NO SCALING
1	VERY SLIGHT SCALING (1/8" (3.2 MM) DEPTH, MAX, NO COARSE AGGREGATE VISIBLE)
2	SLIGHT TO MODERATE SCALING
3	MODERATE SCALING (SOME COARSE AGGREGATE VISIBLE)
4	MODERATE TO SEVERE SCALING
5	SEVERE SCALING (COARSE AGGREGATE VISIBLE OVER ENTIRE SURFACE)

Rapid Chloride Permeability

AASHTO T277

Project: RI04-051

Sample #	Product	Coulomb 1	Coulomb 2	Coulomb 3	Average	Average by Sealer	Rank
5RVWA077	Star Macro 1:1	1677	2286	1915	1959	1959	1
5RVWA076	Star Macro F/S	2080	2757	2123	2320	2320	2
5RVWA078	Star Macro 1:3	2302	2583	2317	2401	2401	3
5RVWA046	Silane	2202	2692	2360	2418	2879	4
5RVWA045	Silane	3361	3567	3094	3341	2879	4
5RVWA075	Star Macro Control	3091	3469	3404	3321	3321	5
5RVWA031	LinSeed Oil	3697	4140	3566	3801	3545	6
5RVWA032	LinSeed Oil	3179	3323	3364	3289	3545	6
5RVWA003	Radcon # 7	3351	4004	4467	3941	3771	7
5RVWA004	Radcon # 7	3510	3986	3305	3600	3771	7
5RVWA018	Chem Tech One	3528	3829	3806	3721	3798	8
5RVWA017	Chem Tech One	4091	4157	3379	3876	3798	8
5RVWA059	Control	4095	3900	3542	3846	3914	9
5RVWA060	Control	4113	4439	3392	3981	3914	9

Chloride Permeability	Charge Passed (coulombs)	Type of Concrete
High	4,000	High w/c ratio (=>0.6)
Moderate	2,000-4,000	Mod. w/c ratio (0.4-0.5)
Low	1,000-2,000	Low w/c ratio ("Iowa" dense concrete)
Very Low	100-1,000	Latex Mod. Concrete Internally sealed
Negligible	100	Polymer Impregnated Polymer concrete

Absorption Re-Tests ASTM C642 Modified (MoDOT)

	original weight	Weight with coating	March 31,2006 48 hr soak	48 hr - %Absorption	Avg.	May 18, 2006 50 day soak	50 day % Absorption	
Silane 55 #3	1.8723	1.8833	1.8997	0.870811873	0.669	1.9493	3.504486805	2.604
#3-2	1.8929	1.9011	1.91	0.468150018		1.9335	1.704276472	
Star Macro 1:1 #4	1.8666	1.8806	1.8854	0.25523769	0.364	1.8975	0.898649367	1.094
1:1 #4-2	1.8775	1.8852	1.8941	0.472098451		1.9095	1.288987906	
3:1 #5	1.9061	1.9155	1.9226	0.370660402	0.336	1.9402	1.289480553	1.235
3:1 #5-2	1.8896	1.8967	1.9024	0.300521959		1.9191	1.180998576	
Radcon #7 8	1.8794	1.8875	1.9445	3.01986755	2.967	1.968	4.264900662	4.240
#7, 8-2	1.8843	1.8908	1.9459	2.914110429		1.9705	4.215147028	
Chemtech 1 #9	1.8991	1.9083	1.9682	3.138919457	3.238	1.9676	3.10747786	4.420
#9-2	1.8826	1.8877	1.9507	3.337394713		1.9959	5.731842984	
10 Linseed oil	1.8869	1.895	1.9468	2.733509235	2.519	1.9877	4.89182058	4.424
2	1.9031	1.9086	1.9526	2.30535471		1.9841	3.955779105	
Control # 6	1.9151	1.9244	1.9792	2.847640823	2.957	2.0129	4.598836001	4.523
#6-2	1.8596	1.866	1.9232	3.065380493	2.981	1.949	4.448017149	4.526
Control #7	1.9113	1.9232	1.9819	3.052204659	3.006	2.0153	4.788893511	4.528
#7-3	1.8656	1.8822	1.9379	2.959302943		1.9625	4.266284136	

Revised 6/14/06- found mistake in recorded weight

Trial Using Epoxy for coating (2nd set) of Absorption Test on B2 Concrete using Chem Tech One Reactive Silicate Sealer

	Date Tested		12/21/2005		12/22/2005		2/9/2006
	Core #	Wt./Dry	Wt.24hrs	% Abs	Wt.48hrs	% Abs	50 Days*
Control - No coating	132	960.4	986.7	2.74	989	2.98	*
	133	972.8	999.5	2.74	1001.6	2.96	*
Sealed using ASTM C672 (epoxy coated	134	943.2	944	0.08	944.2	0.11	*
except top surface)	135	979.6	980.5	0.09	980.8	0.12	*
Sealed whole specimen per ASTM D6489	136	986.6	1003.1	1.67	1005.5	1.92	*
	137	974.8	991.6	1.72	993.9	1.96	*

* Tests specimens were not retained for 50 day tests. Re-tests using the epoxy coated specimens was started on a whole new set of samples on 3/9/06. Decided to use ASTM C672, not D6489.

Oven Dried Weights			12/19/2005
	9:30	11:30	
Core #	wt./24 hr.	wt./26 hr.	% diff.
132	961.2	960.3	-0.09
133	973.7	973	-0.07

Absorption Test , OHD L-40

Oklahoma DOT - Method of Core Test For Determining Depth of Penetration of Penetrating Water Repellent Treatment Solution into Portland Cement Concrete
ASTM C642 Modified

Project: RI04-051

Sample Number	Treatment	% Absorbtion @ 48 hr	Rank
5RVWA054-A	Silane 55	0.4062	1
5RVWA094-A	Star Macro 1:3	0.4131	2
5RVWA093-A	Star Macro 1:1	0.8346	3
5RVWA054-B	None	1.0508	4
5RVWA092-A	Star Macro F/S	1.0787	5
5RVWA093-B	None	1.1159	6
5RVWA094-B	None	1.1829	7
5RVWA092-B	None	1.3187	8
5RVWA012-A	Radcon # 7	2.5233	9
5RVWA068-A	None	2.9119	10
5RVWA068-B	None	2.9281	11
5RVWA026-B	None	2.9849	12
5RVWA012-B	None	2.9969	13
5RVWA026-A	Chem Tech 1	3.0932	14
5RVWA040-A	Linseed Oil	3.4690	15
5RVWA040-B	None	3.8002	16

Sample Number	Treatment	% Absorbtion @ 50 days	Rank
5RVWA026-A	Chem Tech 1	4.4224	1
5RVWA094-A	Star Macro 1:3	4.4296	2
5RVWA012-A	Radcon # 7	4.441	3
5RVWA092-B	None	4.4526	4
5RVWA040-A	Linseed Oil	4.4532	5
5RVWA068-A	None	4.4544	6
5RVWA093-B	None	4.4584	7
5RVWA093-A	Star Macro 1:1	4.4586	8
5RVWA068-B	None	4.4606	9
5RVWA012-B	None	4.465	10
5RVWA026-B	None	4.466	11
5RVWA040-B	None	4.468	12
5RVWA054-B	None	4.468	13
5RVWA092-A	Star Macro F/S	4.468	14
5RVWA054-A	Silane 55	4.4738	15
5RVWA094-B	None	4.4806	16

Crack Sealing Test
AASHTO T259 Modified

Project: RI04-051

Sample Number	Surface Treatment	Crack Measurement		Average of Measurement		Elapsed Time Unsealed	Elapsed Time Sealed	Sealed Time/Unsealed Time= (2X unsealed time minimun to pass)	Pass	Rank
5RVWA048	Silane 55	0.05 0.05 0.05	mm mm mm	0.050	mm	12 seconds	777600 sec. 9 days (stopped test)	64800	Yes	1
5RVWA080	Star Macro 1:1	0.05 0.05 0.08	mm mm mm	0.060	mm	9 seconds	59 seconds	6.55	Yes	3
5RVWA033	Linseed Oil	0.05 0.05 0.13	mm mm mm	0.0767	mm	21 seconds	53 seconds	2.52	Yes	5
5RVWA006	Radcon #7	0.13 0.64 0.13	mm mm mm	0.300	mm	3 seconds	2 seconds	0.66	No	6
5RVWA019	Chem Tech 1	0.23 0.08 0.25	mm mm mm	0.187	mm	9 seconds	3 seconds	0.33	No	7
5RVWA061	Control	0.41 0.33 0.23	mm mm mm	0.323	mm	6 seconds	N/A	N/A	N/A	8

Summary of Sealer Testing

	Test Rank A	B	C	D	E			
	Resistance to chloride Ion Penetration	Scaling Resistance to Deicing Chenmicals	Rapid Chloride Permeability	Absorption Test - Oklahoma Method		Overall Ranking (A+B+C+E)/4	Crack Sealing Test	
	AASHTO: T 299	ASTM C672	AASHTO T277	ASTM C642 Modified			ASTM T259 Modified	
	Ponding Panels			OHD L-40				
				* 48 hr.	** 50 days			
Linseed Oil	1	1	5	15	5	**1**	5	P
Linseed Oil	1	1	5	15	5		5	P
Star Macro 1:3	3	6	3	2	2	**2**	4	P
Star Macro 1:3	3	6	3	2	2		4	P
Radcon #7	5	3	6	9	3	**3**	6	
Radcon #7	5	3	6	9	3		6	
Chem Tech 1	4	7	7	14	1	**4**	7	Ind.Lab A-672 didn't meet std.
Chem Tech 1	4	7	7	14	1		7	A-672 didn't meet std.
Star Macro 1:1	7	5	1	3	8	**5**	3	P
Star Macro 1:1	7	5	1	3	8		3	P
None	2	8	8	4	4	**6**	8	
None	2	8	8	6	6	**7**	8	
None	2	8	8	7	7	**8**		
Star Macro F/S	6	4	2	5	14	**9**	2	P
Star Macro F/S	6	4	2	5	14		2	P
Silane 55	6	2	4	1	15	**10**	1	P
Silane 55	6	2	4	1	15		1	P

* - #8,10,11,12,13,16 - None (controls for other sealers)

** - #9,10,11,12,13,16 - None (controls for other sealers)

P = passed test criteria

Appendix C

Special Test Methods From Other States

Test 4. ASTM C642, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

Test 5. Crack Sealing Test, AASHTO T259 Modified

OHD L-39
METHOD OF TEST FOR
WATER IMMERSION TEST FOR DETERMINING PERCENT MOISTURE ABSORPTION OF CORE TAKEN FROM PORTLAND CEMENT CONCRETE TO WHICH WATER REPELLENT SOLUTION HAS BEEN APPLIED

I. **SCOPE.** This method covers the determination of percent moisture absorption in hardened concrete to which penetrating water repellent treatment solution has been applied.

II. **TEST SAMPLE.**

A. One core, four (4) inches (I0 cm) diameter by four (4) inches (10 cm) length retrieved from the surface of Portland Cement concrete to which penetrating water repellent treatment solution has been applied.

B. The core shall be retrieved no sooner than five (5) days after the penetrating water repellent solution has been applied to the surface of the Portland Cement concrete.

Ill. **PROCEDURE.**

A. The core shall be oven dried as designated by ASTM C-642 Test Method 5.1. The core shall then be sealed with paraffin on the sides and bottom. The paraffin shall overlap the top edge of the core inch (3mm). The core shall be weighed to determine the oven dry weight of the core and paraffin. This weight shall be designated as "A.

B. The core, processed in accordance with Ill, A, shall be immersed in a suitable receptacle, covered with tap water and the procedure as designated by ASTM C-642 Test Method 5.2 shall be followed to determine the soaked, surface dried weight of the core and paraffin. This weight shall be designated as "B".

C. Determine the percent moisture absorption of the core using the following formula:

$$\frac{B - A}{A} x\ 100$$

IV. **REPORT.** Report weights A and B and percent moisture absorption.

Test 5. Crack Sealing Test, AASHTO T259 Modified.

The following is an excerpt from the Ohio DOT 2005 Construction and Materials Specifications, - Section 705.24, Subsection D, with the border around it, describes the test.

705.24 Soluble Reactive Silicate Provide a soluble reactive silicate (SRS) that is a blend of $Na/K/Fl_xSiO_x$ (sodium, potassium, fluoro or other silicate), surfactants, polymers, and stabilizers capable of thoroughly saturating and sealing concrete. The treatment system will meet the following performance requirements:

A. Scaling Resistance - Treated concrete will pass ASTM C 672, Scaling Resistance test with a rating of 'No Scaling' after 100 cycles (non-air entrained concrete) as compared to "Severe Scaling' on untreated concrete

B. Absorption - The absorption of treated concrete under total immersion will not exceed 1.0 percent after 48 hours or 2.0 percent after 50 days (ASTM C 642, non-air entrained concrete). Concrete should be proportioned and mixed in accordance with ASTM C 672.

C. Skid resistance - The skid resistance of treated concrete pavement will not be reduced by more than 10 percent as compared to the same untreated pavement. ASTM E 274 using ASTM E 501 ribbed tire at 40 mph (64 kph), five test average.

D. AASHTO T 259 as modified. The standard T 259 Resistance of Concrete to Chloride Ion Penetration will; be modified as follows:

In addition to section 3.1, intentionally break the specimens so they have a full depth crack through the middle of the slab.

Install section 3.2 dams around the perimeter of the re-assembled, cracked, concrete specimens. Caulk around the perimeter of the dam to assure that only the crack and the concrete will allow water to pass through or be absorbed. After assembly, measure the crack width at three locations and report the crack width.

Perform the ponding of 3.4 until the 3% solution comes through the specimen's crack. Record and report he time required for the solution to appear through the specimen's crack. Remove the solution from the specimens and re-dry according to 3.3 (T 259).

After drying apply the SRS to the specimen's top surface at the manufacturer's recommended rate of application. Record and report the rate of application. Air dry the SRS coated dammed sample specimens for 7 days. After 7 days, re perform the ponding with 3% chloride solution until solution comes through the specimen's crack or 14 days. Record the time the till the ponded solution comes through the crack.

Acceptable SRS materials will have a value of 2 or more when the ponding time before SRS application is divided into the ponding time after SRS application.

Sections 3.5, 3,6, 4.1,4.2 and 5.1 (of T 259) will not apply.

Have tests performed by an approved independent testing facility acceptable to the Department.

Submit test data and a one quart (one liter) a technical data sheet and the MSDS to the OMM for approval

Furnish materials according to the Department's Qualified Products List (QPL)

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